Title

Can Blue Carbon Further Conservation? Approaches to Conservation through a Portfolio of Blue Carbon Options: A Case Study in The Bahamas

Author

Mandoske, Jaclyn

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Can Blue Carbon Further Conservation?

Approaches to Conservation through a Portfolio of Blue Carbon Options: A Case Study in The Bahamas

Jaclyn Mandoske | Master of Advanced Studies in Marine Biodiversity and Conservation
Scripps Institution of Oceanography, UC San Diego

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ABSTRACT

Understanding the value of nature's services is critical to conservation and development decisions that balance the long-term needs of people and the environment.

The world is currently facing major losses in biodiversity and habitats, and climate change is expected to exacerbate risks to natural and human systems. The ability of coastal ecosystems to store and sequester carbon, known as "blue carbon" has become increasingly important in understanding the potential of blue carbon in climate change mitigation and how land use changes can contribute to climate change. A new paradigm shift in conservation is increasingly focused on more people-centered approaches and connecting the value of ecosystem services to people. This is particularly true for small island nations largely dependent on their natural resources and vulnerable to climate change impacts. Through a case study in The Bahamas, I reached out to stakeholders to better understand their needs and knowledge of blue carbon and conducted a spatial analysis on the current distribution of blue carbon at a national scale in The Bahamas and on Andros Island. I further evaluated how carbon storage and sequestration are likely to change under several future management scenarios by total net sequestration, as well as net present economic value of blue carbon. These results were further used to evaluate how a blue carbon analysis could be useful in advancing conservation. Drawing on the results from the study, I present a portfolio of blue carbon options that could benefit from a blue carbon analysis, which range from direct government incentives, to direct local incentives, to indirect altruism as various avenues to achieve blue carbon conservation. This portfolio of options can provide decision-makers with the necessary knowledge on blue carbon to implement a range of conservation options to best meet their needs, and this approach can be replicated and applied to other nations as well.

Keywords: ecosystem services, blue carbon, conservation, spatial analysis, participatory stakeholder approach

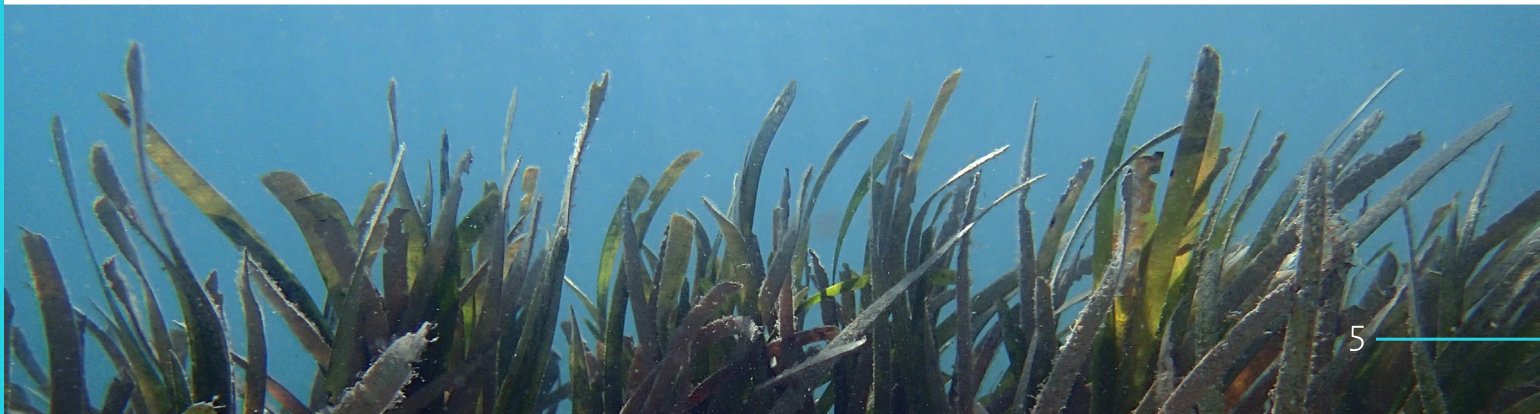
1. INTRODUCTION

1.1 Ecosystem services

Nature provides an array of essential services that benefit people. These services are collectively known as ecosystem services and they encompass a wide range of benefits including provisioning services such as food, regulating services such as gas regulation and climate control, supporting services such as soil formation, as well as cultural services such as tourism and recreation (MEA 2005). A growing body of research aims to quantify the economic value of the world's natural capital and its contribution to human wellbeing (Guerry et al. 2015). However, today the world is facing major losses in global biodiversity and habitats (Brooks et al. 2002), and declines in ecosystem health and functioning continue to occur due to the combined effects of habitat degradation and loss, pollution, overexploitation, climate change, and other global and local stressors (MEA 2005). As ecosystems are degraded or destroyed, they lose their ability to provide fundamental services people depend upon (Lau 2013).

1.2 Climate change impacts to people and ecosystems

Climate change is expected to exacerbate risks to both natural and human systems (IPCC 2014) and there is a collection of research on the varied ecological responses of natural systems under global change (Walther et al. 2002). Increasing temperatures, changing rainfall patterns, and sea level rise are all projected impacts of increasing atmospheric carbon dioxide levels that can pose threats to ecosystems (Ellison 2015). While it is widely recognized that climate change impacts will affect the distribution and functioning of ecosystems, there is now increasing attention on the significance of ecosystems in further influencing climate (Foley et al. 2003). One of the functions of ecosystems is regulating greenhouse gases through sequestering and storing carbon (Farber et al. 2006), and these systems may play critical roles in climate change.



1.3 What is “blue” carbon?

Carbon stored and sequestered by coastal environments, such as mangroves, seagrasses and saltmarshes, is increasingly being referred to as “blue carbon” due to their significant contribution to carbon storage (Figure 1), largely due to the carbon content in the soils as well as high rates of carbon burial in soils (Mclead et al. 2011). Furthermore, blue carbon habitats have high annual carbon sequestration rates, with mangroves containing two to four times higher rates than tropical rainforests (Murray et al. 2011). Although these coastal vegetated habitats occupy a relatively small extent, they are disproportionately important in global carbon sequestration (Alongi 2012) and have the ability to store and sequester carbon for decades to millennia (Chmura et al. 2003). Because of this, blue carbon habitats have the potential to be major carbon sinks (Mclead et al. 2011), serving to mitigate the effects of climate change.

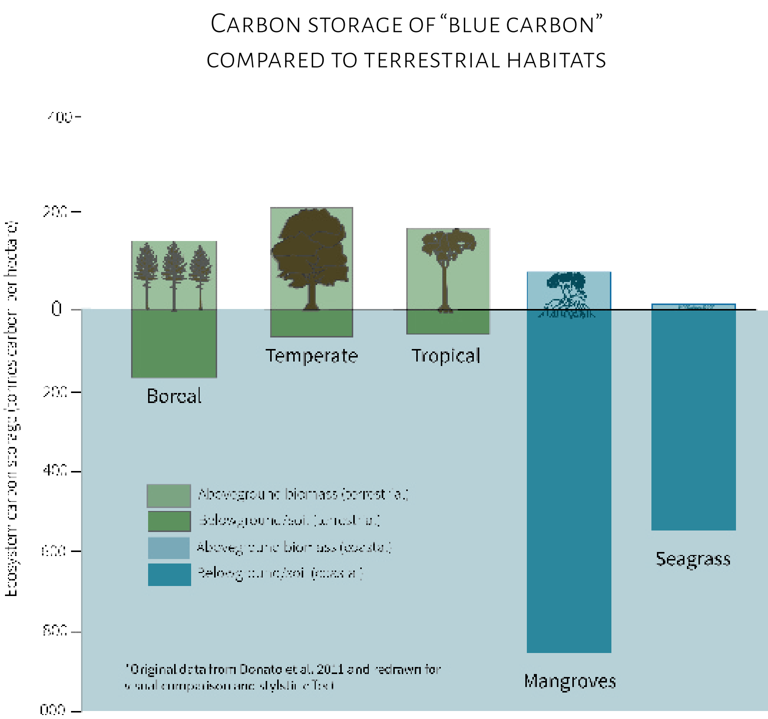


FIGURE 1. | THE SIGNIFICANCE OF “BLUE CARBON”, ORIGINAL DATA FROM DONATO ET AL. 2011 AND REDRAWN FOR VISUALIZATION

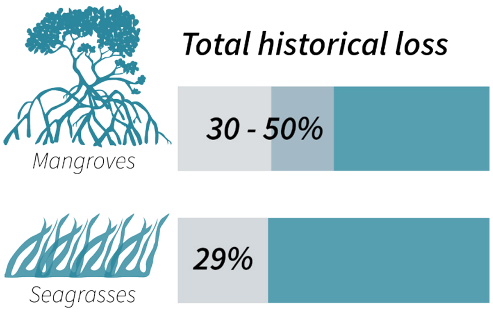


Figure 2. | Total historical loss of mangroves and seagrasses from Valiela et al 2001 and Duarte et al. 2005 data

1.4 Most threatened ecosystems on Earth

However, coastal habitats have seen rapid degradation and depletion (Lotze et al. 2006). Coastal wetlands face many direct and indirect impacts ranging from land use changes and habitat disruption, to sea level rise and development pressures, with current rates of loss ranging from 0.7-7% per year (Valiela et al. 2001, Duarte et al. 2005). Globally, the world has lost 30-50% of mangroves (Valiela et al. 2001) and nearly 50% loss of seagrasses (Duarte et al. 2005) (Figure 2). Coastal habitats are lost at rates four times faster than tropical rainforests (Duarte et al. 2005), and that rate is increasing (Waycott et al 2009). Land use changes currently account for 8 – 20% of global greenhouse gas emissions (Pendleton et al. 2012), and further degradation to coastal habitats has the potential to release large amounts of stored carbon into the atmosphere (Donato et al. 2011). Carbon released from coastal habitats is often not accounted for in national greenhouse gas inventories (Crooks et al. 2011) and it may be a significant further source of carbon emissions.

1.5 Challenges of conservation

As research on climate change mitigation has grown, there has been increasing attention on maintaining and restoring wetlands for their carbon storage and sequestration services through strengthening policy and practical management decisions (Crooks et al. 2011). Yet, many challenges to conservation remain, including institutional challenges due to the fact that conservation occurs in a political context (Buckley 2015), barriers in financing (McCarthy et al. 2002) and opportunity costs (Adams et al. 2010), as well as linking socio-ecological systems that involve government agencies, private organizations, and community stakeholders to ecosystems, functions, and services (Buckley 2015). Just as the challenges of habitat loss and degradation are the result of human choices, the solutions to effective conservation also lie with the actions and decisions of people.

1.6 Paradigm shift in conservation to people-centered

Recently, there has been a paradigm shift in thinking about conservation from the traditional biological conservation approach to more people-centered and community-based conservation (Brown 2003). There is an increase in governments and scientists engaging in innovative approaches to conservation through more integrated management efforts (Arkema et al. 2015). These integrated efforts are addressing both conservation and development goals (Tallis et al. 2008) and there is increasing attention on the importance of science and policy to maintain ecosystem services that support human socioeconomic wellbeing (Ruckelshaus et al. 2013). A variety of tools currently exist to utilize ecosystem services approaches to inform decision-making, and while these approaches simplify, to an extent, the biophysical or socioeconomic processes, these first-order analysis are often what decision-makers need to inform science to policy decisions (Ruckelshaus et al. 2013).

1.7 Available tools for policy-makers

In terms of blue carbon conservation, there are currently a variety of policy instruments, public and private options, and international mechanisms that are available to potentially improve conservation outcomes. These include economic incentives, carbon markets, offsets, and payments for ecosystem services (Wunder 2014), as well as non-market options including international multi-lateral mechanisms such as the United National Framework Convention on Climate Change (UNFCCC) "Nationally Appropriate Mitigation Actions" (NAMAs) and Reducing Emissions from Deforestation and Degradation (REDD) (Ullman et al. 2013). Because these approaches may be suitable differently across contexts, there is a need to develop and communicate a portfolio of blue carbon policy and conservation options to provide decision-makers with necessary tools and knowledge on blue carbon with a range of options to utilize this information to best meet their needs (Figure 3).

Figure 3. | Example of a portfolio of available tools for policymakers

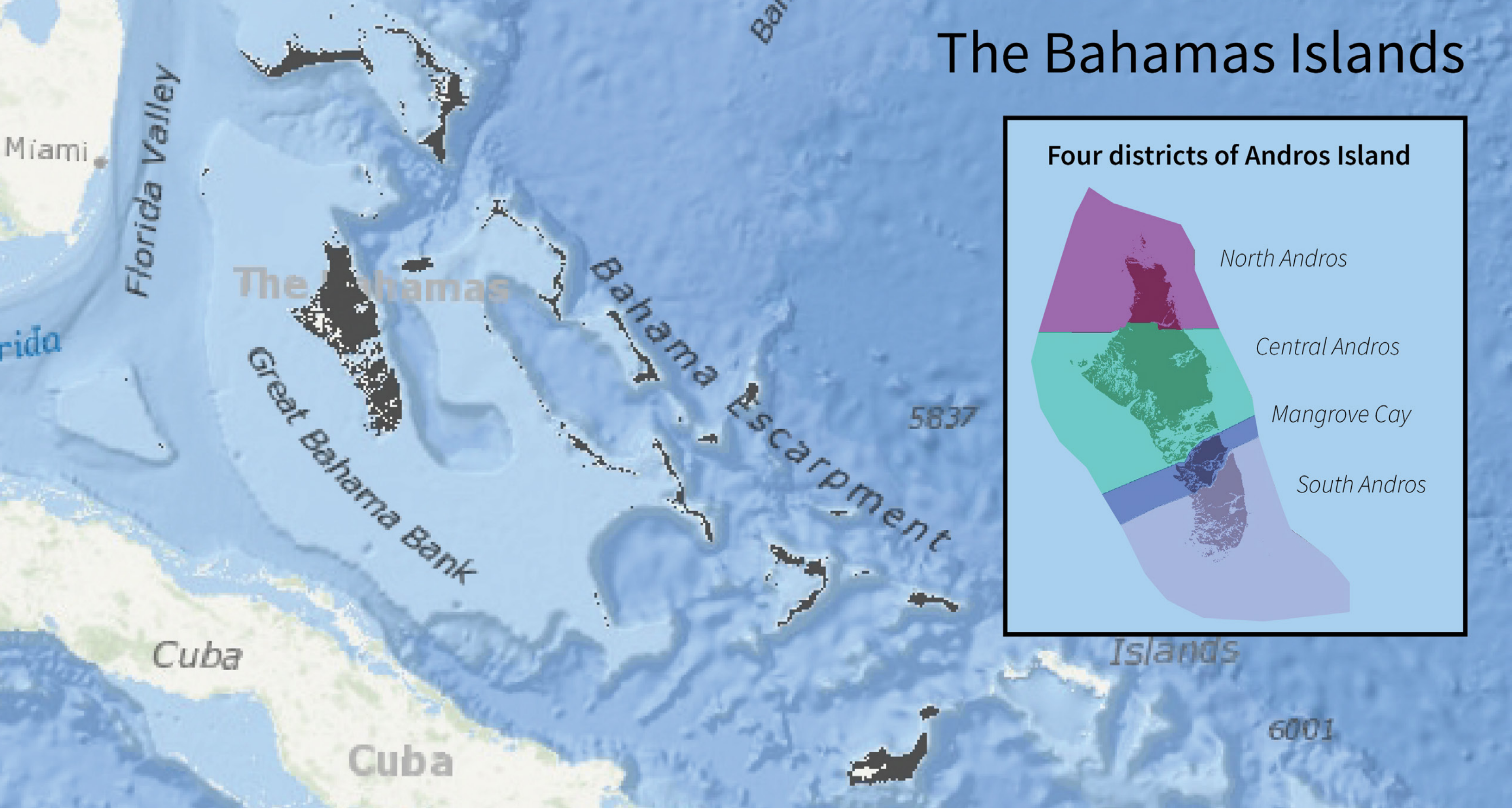


Figure 4. | map of the bahamas islands and insert of andros island, including subregions of north, central, mangrove cay and south

1.8 Purpose of study and objectives

The need for more accessible options to improve conservation in light of the urgent threat of climate change comes into stark relief for small island nations. Through a case study in The Bahamas (Figure 4), I engaged with stakeholders to understand their knowledge of blue carbon and interest in utilizing this resource to further conservation. I conducted a spatial analysis on the distribution of blue carbon on Andros Island, The Bahamas and developed a portfolio of options to utilize this analysis to further an ecosystem service approach to conservation that includes the interest of people. In this paper, I explore these issues in The Bahamas and ask:

1) ***How does carbon storage and sequestration vary spatially across The Bahamas and Andros currently?***

2) ***How does the distribution of blue carbon storage and sequestration vary under four future management scenarios?***

3) ***How can a blue carbon analysis be used to further conservation?***

2. ADVANCING BLUE CARBON SCIENCE AND POLICY IN THE BAHAMAS

The Bahamas is an island nation of the western tropical Atlantic with a population of nearly 400,000 people. The vast majority of its population, 70 percent, lives in Nassau, the nation's capital, with the remaining residents living in the outer Family Islands of over 700 islands and cays. The Bahamas is heavily dependent on tourism, as it makes up nearly 60 percent of the nation's Gross Domestic Product (GDP), followed by offshore banking (Dupuch 2005). While The Bahamas has one of the highest GDPs of the western hemisphere, there is an uneven distribution of income, which gives the appearance of wealth even though many residents, particularly those who live on the outer islands, are low-income and heavily dependent on natural resources. Like other island nations, The Bahamas has a wealth of coastal habitats including mangrove forests and extensive seagrass habitats along its shallow continental shelves. As a member of the United Nations Small Island Developing State (SIDS), The Bahamas has a continued need to further development and provide economic opportunities to its residents. Coastal development is a main driver of coastal habitat loss, and as these habitats are depleted, residents may loose these essential ecosystem services, as well as face increased risks from the loss of coastal habitats in providing barriers from storms and hurricanes.

In response to these challenges, The Bahamian government, local non-governmental organizations and the private sector have been working on sustainable development initiatives to equip public institutions with necessary resources and mobilize partnerships to improve social, economic, and environmental goals. This includes The Bahamas National Development Plan and more specifically, the Master Plan for Sustainable Development on Andros, with a planning process that included ecosystem services assessments on the contribution of habitats in providing coastal protection, supporting the island's lobster fishery and tourism. Other conservation initiatives include The Bahamas Integrated Coastal Zone Management (ICZM) plan aimed at improving the quality of life for residents dependent on marine and coastal systems, as well as the expansion of the current Marine Protected Area (MPA) network to an additional 10% by 2020, which is being driven by a coalition of governments in the Caribbean Challenge Initiative. Furthermore, the Department of Forestry is in the process of establishing protocols to begin baseline carbon sampling and monitoring as an initial step in the UN REDD process. A study in 2015 funded by the Global Environmental Facility (GEF) conducted research to fill in knowledge gaps on ecosystem-based management, which included a component on carbon sequestration of specific mangrove restoration efforts on Abaco and Andros. However, while some of these initiatives have considered ecosystem services of coastal habitats, there remains little work on the value of blue carbon nationally across The Bahamas, how future scenarios may affect the delivery of carbon services, or avenues in which blue carbon can be further utilized.

To advance the science and policy related to blue carbon in The Bahamas, I reached out to government officials and stakeholders in The Bahamas to understand their state of knowledge on blue carbon. I also reached out to non-governmental organizations (NGOs) in order to build off the ecosystem services work in the Master Plan for Sustainable Development on Andros and understand future management scenarios, cumulative risk to ecosystems, and learn how to quantify ecosystem services. I then conducted a spatial analysis to quantify the distribution of blue carbon currently on Andros and across several future management scenarios and finally developed and communicated a portfolio of blue carbon options in The Bahamas to utilize the analysis in a way that can be applicable in other countries as well.

Nassau, The Bahamas

3. METHODOLOGY

3.1 Overview

In order to understand the role of blue carbon in furthering conservation, I worked with stakeholders, government officials of The Bahamas, and NGOs to understand the current state of knowledge and interest of blue carbon. I conducted a spatial analysis of blue carbon habitats for mangroves and seagrasses to explore variation at a national scale, and on Andros to evaluate current blue carbon distribution and changes in carbon sequestration or emissions under alternative development scenarios. I then considered these results through the context of a portfolio of blue carbon options that provides various ways to utilize a blue carbon analysis and contribute to conservation. Assumptions and limitations to the model are further discussed below.

3.2 Participatory stakeholder engagement

Stakeholder engagement has been shown to help enhance inclusive decision-making and build social capacity (Mathur et al. 2008). In The Bahamas, I reached out to the Department of Forestry and Office of the Prime Minister (OPM) to learn about the state of knowledge on blue carbon, discuss current levels of awareness on blue carbon and ecosystem services, and learn if there are any current policies or initiatives related to blue carbon. The meeting led to fruitful discussions about the Department's interest in establishing carbon-monitoring protocols as a first step to be eligible for the UN Framework for Reducing Emissions from Deforestation and Degradation (REDD) mechanism, which contracts with governments and offers payments as incentives to maintain health and intact forests with carbon-rich ecosystems. From the discussion of blue carbon came an interest in potentially adding seagrasses to the baseline-monitoring program after discussing how seagrasses occur to a large extent around Andros and across The Bahamas. Furthermore, the Department of Forestry was interested in learning what policy framework would be necessary to implement a blue carbon national policy. They communicated a variety of challenges of initiating blue carbon programs including their uncertainties with who would oversee implementation and verify carbon monitoring, what is the source of funding, and how to coordinate and collaborate among government agencies as coastal habitats and associated blue carbon options could include jurisdictions across the Department of Forestry, Ministry of the Environment, Department of Tourism, and other relevant agencies.

Andros Town, The Bahamas

Further Stakeholder interactions also included weekly calls with government officials and NGOs in The Bahamas to discuss an economic valuation of marine protected areas (MPAs) to help inform expansion of the MPA network to 20% by 2020. These calls included weekly discussions on different ecosystem service analyses, including blue carbon, with the purpose of the calls to engage in an iterative approach for stakeholders to contribute and inform the analysis and allow for an adaptive, co-development process of knowledge. This approach allows for researchers to gain insightful knowledge from practitioners and resource managers, while at the same time allows researchers to communicate their process with practitioners who can then better understand the value and use of ecosystem service analyses. The goal of the stakeholder process is to learn about current and future needs, share knowledge, and provide resources that can be useful in addressing practical conservation and sustainable development planning decisions.

3.3 Estimating blue carbon at a national scale

In order to perform an analysis of blue carbon across The Bahamas, I performed a variety of necessary steps including obtaining the appropriate spatial habitat data layers, using a global predictive model on mangrove biomass from the literature, and formatting the spatial layers to run an analysis using the InVEST Coastal Blue Carbon model.

The InVEST Coastal Blue Carbon model is an open-source modeling software programs development by the Natural Capital Project (NatCap) based on a production function approach to evaluate how changes in ecosystem function are likely to affect the delivery or flow of ecosystem services (http://www.naturalcapitalproject.org/invest/). I used the coastal blue carbon model to analyze carbon storage and sequestration currently across The Bahamas. Using spatially explicit maps as inputs, the model can be adapted to unique user specifications, ranging from a high-level analysis with limited data, to a more detailed analysis with finer control of input data, including information on the effects of different types of disturbances to coastal habitats.

Mangrove Cay, The Bahamas

To conduct a national scale analysis, I gathered Geographic Information Systems (GIS) spatial data layers for The Bahamas from The Nature Conservancy (TNC) database, which contains data collected through both participatory stakeholder engagements as well as through working with regional partners to generate, collect, and share spatial layers. Two habitat data layers were used for this project: the spatial extent of mangroves and seagrass across The Bahamas compiled from Landsat data at 30m spatial resolutions. These layers were then combined with data from the literature on carbon biophysical values for both mangroves and seagrasses.

Mangroves carbon values are known to have general increasing trends in biomass with decreasing latitudes (Alongi et al. 2014), but it is also known that carbon values can vary considerably based on specific environmental conditions and circumstances (Alongi et al. 2012). However, there have been an increasing number of comprehensive reviews on the science of blue carbon (Alongi 2014, Chmura et al. 2003, Sifleet et al. 2011) as well as papers that propose spatially explicit models to predict carbon values (Hutchinson et al. 2013, Jardine and Siikamaki 2014).

For this study, I calculated aboveground mangrove biomass based on the global predictive model proposed by Hutchinson et al. 2013. This model is based on four climatic variables of quarterly extremes in temperatures, precipitation and seasonality (Hutchinson et al. 2013). Using spatial analysis, I created a layer on aboveground biomass using following the Hutchinson et al. 2013 model and publically available data from Worldclim.org. I created a second layer to calculate belowground biomass following a procedure in Hutchinson et al. 2013 based on an allometric relationship between aboveground and belowground biomass. I added the layers together and classified them by equal interview to create ten class values for mangrove biomass across The Bahamas islands. Because the climate data provided values only for land and the habitat layers extended into coastal regions, I used an Euclidean allocation spatial analyst tool to approximate biomass values that fall outside land. I then extracted by mask to produce a spatial layer of mangroves that contained the biomass data calculated above. This biomass variation data was used only for The Bahamas national scale analysis, and biomass values ranged from 167.5 tons per hectare (t ha^{-1}) to 200.9 t ha^{-1}.

3.4 Blue carbon current and future on Andros

To evaluate the distribution of blue carbon on Andros currently and across several future management scenarios, I gathered spatial layers data on mangroves and seagrasses across Andros, utilized the outputs of the NatCap's stakeholder engagement future management scenarios and habitat risk assessment maps, and gathered carbon biophysical and economic values to perform a spatial analysis of carbon content currently on Andros and over time.

The mangrove spatial dataset used in this analysis represents the extent of mangroves on Andros, and was originally derived from Landsat photos at 30-meter spatial resolution with density classes for dense and sparse mangroves from 5-m RapidEye imagery (NatCap database 2017). The seagrass dataset represents a merger of two separate spatial data layers: a finer resolution seagrass data classified into sparse and dense submerged vegetation, and data from Landsat 7 imagery analysis with limited ground-truthing to derive classes of sparse, medium and dense seagrass (NatCap database 2017).

I obtained future management scenarios maps from the NatCap's work on ecosystem services assessments for the Ecosystem-based Development project on Andros Island, which was conducted with funding from the Inter-

South Andros, The Bahamas

Current and Future Scenario Maps of Andros Island with Stressors

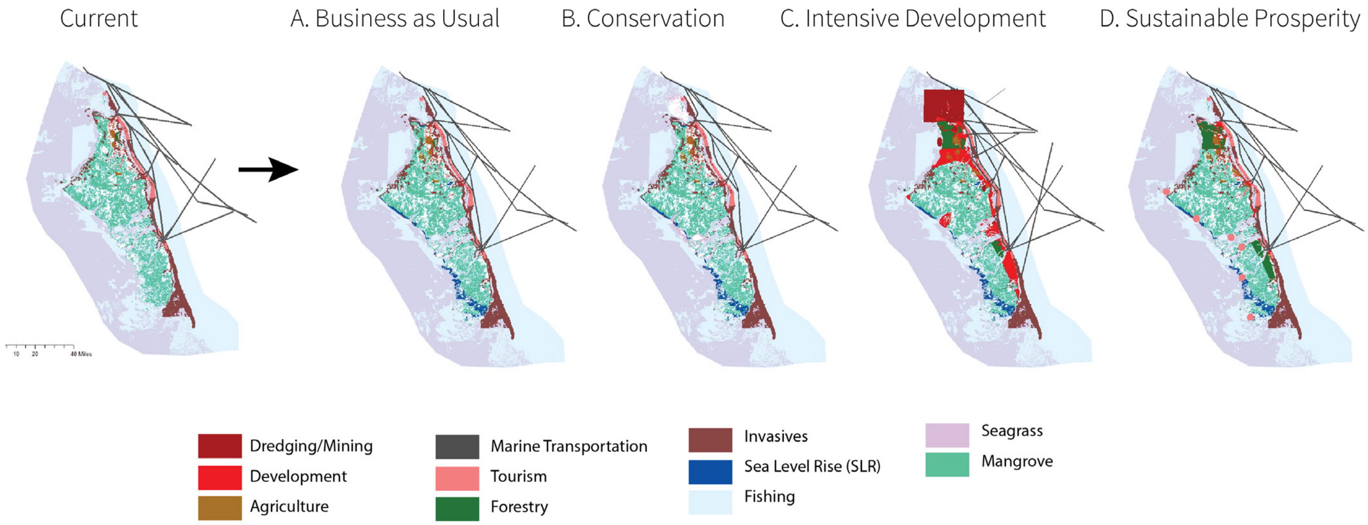


Figure 5. | Future scenario maps of Andros Island, The Bahamas with stressors. Maps were development through participatory stakeholder approach from NatCap and core partners in The Bahamas.

American Development Bank (IDB), the Office of the Prime Minister (OPM), and The Nature Conservancy (TNC). Researchers and collaborating partners conducted various in-person meetings, including both public and private stakeholder events to learn about current activities and discuss in detail how these may change in the future. Researchers then digitized hand-drawn maps to create GIS layers of nine activities, or “stressors” and outlined how these activities would change across four future development scenarios: A. Business as Usual, B. Conservation, C. Intensive Development, and D. Sustainable Prosperity (Figure 5). These nine activities include: dredging and mining, development, agriculture, marine transportation, tourism, forestry, invasive species, fishing and sea level rise.

Furthermore, knowing where the nine stressors occur spatially is important, yet this information does not describe how those stressors are likely to impact the structure and function of ecosystems, and consequentially the delivery or flow of ecosystem services. To better understand how scenario stressors are likely to influence the functionality of habitats, I utilized the outputs of another model from the InVEST suite, the Habitat Risk Assessment (HRA) model, which determined the relative risk of habitats from the stressors in each scenario. The model relies on two dimensions of risk: “exposure” and “consequence”, where exposure refers to the extent to which a habitat is likely to experience risk, and consequence, which refers to both the sensitivity of the habitat to a particular stressor and natural resilience of the habitat (Arkema et al. 2014). The model produces maps with scores for exposure and consequences ranging from 1 (lowest) to 3 (highest) risk. The HRA model can be adapted to various habitats and associated risks, and is part of the open-source software programs available through the NatCap website (Sharp et al. 2014). For this study, I used HRA maps for mangroves and seagrasses as input maps for the current scenario and four future scenarios (Figure 6).

For the carbon biophysical values, due to the difficultly of applying the spatial variation in biomass to the HRA input maps, I decided to use the average biomass value for the entire island. Average aboveground biomass was calculated to be 134.5 t ha^{-1} and belowground biomass 47.13 t ha^{-1}. These values were added together for a mangrove biomass carbon value of 181.41 t ha^{-1} on Andros, and then I further calculated that 41.5% of the biomass is carbon for a mangrove biomass carbon value of 276 t C ha^{-1} (Bouillon et al. 2008).

Maps of Habitat Risk

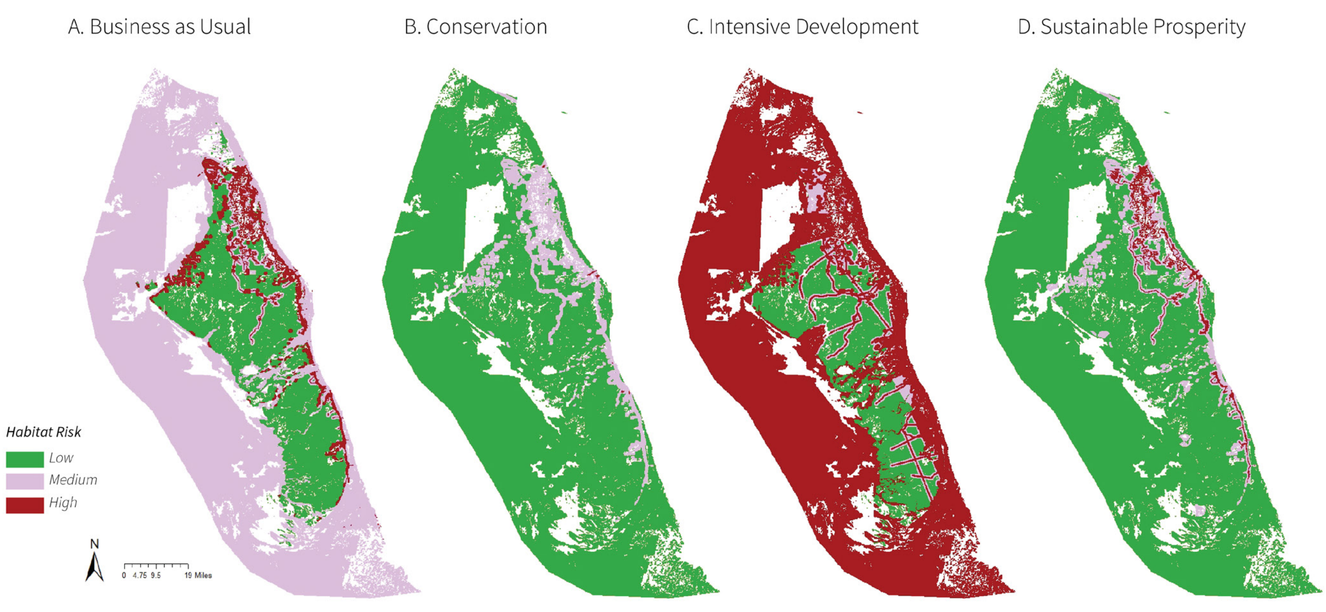


FIGURE 6. | MAPS OF HABITAT RISK AS INPUTS INTO INVEST COASTAL BLUE CARBON MODEL

3.5 Literature review on carbon biophysical and economic values

In order to gather the appropriate carbon biophysical and economic data for the analysis, I conducted an extensive literature review on carbon values and carbon prices. Due to the lack of available empirical studies on blue carbon on Andros Island or The Bahamas, this study relied on the blue carbon literature to determine the appropriate biophysical values for mangroves and seagrass habitats.

I researched biophysical values for carbon occuring in three main pools: biomass, soil, and litter for mangroves and seagrasses. The biomass values were calculated as listed above for the national and Andros analysis (section *3.3 Estimating blue carbon at a national scale* and section *3.4 Blue carbon current and future on Andros*, respectively), while soil and litter values were gathered from the literature. I also collected values on carbon percent loss from biomass and soils under different types of disturbance as well as habitat-specific rates of decay for carbon emissions after disturbance type.

Mangrove soil carbon values were used based on the average soil carbon value from the study by Jardine and Silkamaki (2014). While the study provides a global predictive model of mangrove soil carbon, time constraints of this project led to the decisions to use the global average of 321 t C ha^{-1} (Jardine and Silkamaki 2014). The mangrove leaf litter value was determined by a third predictive model by Saenger 1993, which relates litter fall to latitude, and the calculated value was 17.48 t ha^{-1} and then further calculated that 41.5% of the biomass is carbon for a mangrove biomass litter carbon value of 2.1 t C ha^{-1} (Bouillon et al. 2008).

Carbon values for seagrass were chosen based on the review paper by Fourqurean et al. 2012, which lists average biomass and soil carbon values for seagrasses in the Western Tropical Atlantic based on data from fifty samples. Seagrass biomass carbon chosen for this study was 0.84 t C ha^{-1} and soil carbon was 150 t C ha^{-1}. Due to the difficulty in finding adequate data on leaf litter carbon for seagrasses, I decided not to include this value in the blue carbon model analysis.

When comparing the chosen values for Andros and The Bahamas across the blue carbon literature, the mangrove values are within global value ranges (Sifleet et al. 2011), but below global averages, which makes sense as The Bahamas is near the upper bounds of mangrove distribution and it is be expected that biomass would be lower than in tropical latitudes (Hutchinson et al. 2013). Since the values chosen for seagrass came from empirical studies near Andros and The Bahamas in the Western Tropical Atlantic, I believe they represent the best currently available data. While further studies on blue carbon on Andros and in The Bahamas would improve the accuracy of the modeled results, I believe these values are appropriate given the context of the study, which is meant to provide an overview of blue carbon resources to help inform decision-making. It has been recognized that policy-makers need at least an order of magnitude estimate to understand the importance of blue carbon habitats and potential emissions and sequestration (Pendleton et al. 2012).

In terms of carbon values from disturbance and subsequent emissions, I gathered data from the literature. I used biomass half-life values of 15 years for mangroves, and 100 days (0.27 years) for seagrass, and soil half-life values of 7.5 years for mangroves and 1 year for seagrass (Murray et al. 2011). These values refer to the exponential decay rate of carbon emissions after disturbance. Further inputs into the model require information relating the percent of carbon stock disturbed after a transition occurs (Sharp et al. 2016). For this study, percent carbon loss from biomass for high-impact disturbance on both mangroves and seagrass were 100% biomass loss, and 50% for medium to low-impact disturbance (Donato et al. 2011). Percent carbon loss from soils from disturbances for mangroves were 66% for high-impact, 50% for medium-impact and 30% for low-impact for mangroves (Donato et al. 2011), and 50% for high-impact, and 10% for medium-and-low impact for seagrass (Murray et al. 2011).

For mangrove soil yearly accumulation, I used the carbon burial estimate of 1.15 t C ha^{-1} per year (y^{-1}) from Bouillon et al. (2008). For seagrass soil yearly accumulation, I used the carbon burial estimate of 0.535 C $ha^{-1}y^{-1}$ from Siikamaki et al. (2013). After expert review regarding values for biomass yearly accumulation, it was decided that the most appropriate value should be zero, as yearly biomass does not contribute to long-term sequestration. Because the significant component of “blue carbon” is in the soil carbon, I believe the soil carbon burial rate reflects the contribution of blue carbon to long-term sequestration and burial, which is important for long-term climate mitigation.

$ 10 PER TON OF CO2E
UPPER-BOUND OF THE VOLUNTARY CARBON MARKET PRICE

$ 13 PER TON OF CO2E
CALIFORNIA CAP-AND-TRADE MARKET CURRENT PRICE AS OF MAY 2017

$ 40 PER TON OF CO2E
US ENVIRONMENTAL PROTECTION AGENCY'S SOCIAL "COST OF CARBON" PRICE

Figure 7. | CARBON PRICES USED FOR ECONOMIC ANALYSIS OF BLUE CARBON IN THE BAHAMAS ANALYSIS

To understand the value of blue carbon, I added three economic prices at constant interest and discount rates to determine the net present value of blue carbon after the specific time horizon. For this study, I chose a range of economic values in order to compare how Andros blue carbon resources could be potentially included in a variety of carbon markets or other payment for ecosystem services mechanisms. I used carbon values of $10 per ton of carbon dioxide equivalents (CO2e), $13/t CO2e and $40/t CO2e (Figure 7). The $10 price was chosen as it represents the floor price of the California carbon cap-and-trade market and is an easily scalable value. The $13/ton price was chose because it is the current California cap-and-trade permit price from the May 2017 auction for one ton of carbon (CARB 2017). The $40/ton price was chosen as it represents the U.S. Environmental Protection Agency's (EPA) best available estimate of the "social cost of carbon", which refers to the cost of damages that carbon dioxide emissions impose on the world (US EPA 2016).

The interest and discount rates were both chosen to be 3%, as this value represents current market rates and aligns with the discount rate used by the U.S. EPA in determining the $40/ton price (US EPA 2016). Using the discount rate that aligned with the social cost of carbon price is useful in order to compare values across the same scale.

3.6 Running the INVEST Coastal Blue Carbon Model

The coastal blue carbon model analyzes changes in carbon content over time (Figure 8). It requires land use/land cover (LULC) raster maps as inputs and produces raster maps as outputs. The input maps for the current scenario (baseline) and the four future scenarios (alternatives) were created using the spatial analysis mosaic to raster tool in ArcGIS to combined HRA maps of mangrove and seagrass habitats to a single raster map per scenario.

The first step of the model is the preprocessor, which requires all map input data including baseline and alternative scenarios. The resulting outputs are a series of three excel files that require additional input by the user: carbon pool initial values, transition matrix, and transient values table. The carbon pool initial values were transformed to express carbon in terms of potential carbon dioxide (CO2) emissions, where the original tons of carbon per hectare values (as listed above in 3.5 *Carbon biophysical and economic values*) to tons of carbon dioxide equivalent per hectare was obtained by multiplying carbon stock by 3.67, which is the molecular weight ratio of CO2 to C. The transition matrix denotes where an overlap has occurred between the baseline and an alternative scenario map, and allows the user to adjust the type of disturbance (low, medium, or high). Lastly, the transient file requires the user to input values for biomass and soil carbon emissions after specific types of disturbance, including decay rates of biomass and soils, percent carbon loss, and yearly carbon accumulation.

The final step is running the coastal blue carbon model. Using the model, each future scenario analysis requires a separate model run. I used a base year used of 2015, with a transition year in 2030 and analysis year in 2040 in order to align with the time horizon used in the planning process for the Andros Master Plan for Sustainable Development work. The carbon price, interest, and discount rates (as listed above in section 3.5 *Literature review on carbon physical and economic values*) were used for a net present value analysis.

The outputs of the coastal blue carbon model include raster maps of carbon stock at the base, transition and analysis years, carbon accumulation between transition years, carbon emissions between transition years, net carbon sequestration between transition years, total net sequestration, and net present economic value.

INVEST Coastal Blue Carbon Model

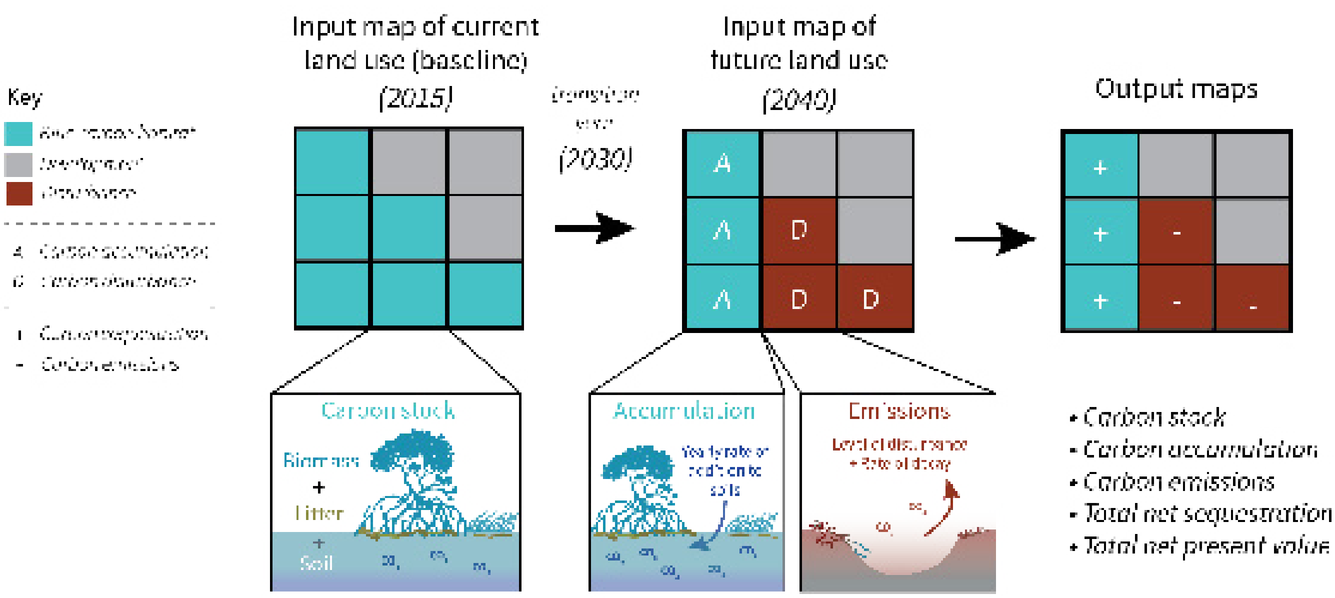


Figure 8. | Overview of process for the coastal blue carbon model. Inputs include a raster map of the baseline scenario, map of the future scenario, and biophysical carbon values in biomass, litter, and soil, yearly accumulation, and rate of emissions after specific types of distrurbance to provide output maps of various metrics.

2.8 Model assumptions and limitations

It is important to note the assumptions and limitations that accompany the use of this model and analysis. The model relies on a relatively simply accounting approach, which does not account for finer detailed changes in blue carbon habitats, such as habitat growth or aging. Furthermore, the model assumes storage and accumulation occur only in the three specified pools, assumes carbon accumulates linearly, disturbed carbon is emitted at an exponential decay rate, and that some activities that may degrade coastal habitats do not affect carbon sediments.

Furthermore, some important assumptions were made in the use of data input maps and carbon values. First, all carbon values used came from the literature and were not taken directly from the area of study. Second, the HRA maps that were used as inputs represent mangrove and seagrass habitat across three rankings of risk: low, medium, and high. In this analysis, we assumed mangrove and seagrasses at a low risk had 100% functionality and assigned them the carbon biophysical values from the literature (as listed above in 2.5 Carbon biophysical data). For mangrove and seagrass habitats at a medium risk, we assumed 50% functionality and assigned carbon values at half the values listed above, and at a high risk, we assumed 0% functionality of habitats and assigned zero carbon storage or sequestration values. These assumptions build off the HRA analysis conducted in Belize by Arkema et al. 2014, which made the same assumptions of habitat risk and functionality for both mangrove and seagrass habitats, and followed up with ground-truthing of modeled habitat risk to empirical evidence of habitat functionality loss.

Even with these assumptions and limitations, I believe this analysis provides a useful first-order approximation of carbon storage and sequestration on Andros Island and in The Bahamas to inform government officials about their blue carbon resources and provides potential options for utilizing blue carbon for conservation.

4. BAHAMAS BLUE CARBON RESULTS

4.1 Current distribution of blue carbon storage in The Bahamas and Andros Island

These results provide spatially explicit values for current carbon storage across The Bahamas (Figure 9) and Andros Island (Figure 10) at the baseline year of 2015, and demonstrate the large extent of blue carbon habitats in the region. Blue carbon stock refers only to the amount of carbon stored in mangrove and seagrass within current biomass, soil, and litter carbon pools and does not provide information regarding sequestration or emissions. However, while they do not represent change over time, these maps do represent total potential carbon emissions that could occur if all habitats experienced future threats that resulted in destruction of habitats or loss of functionality to sequester and store carbon.

The map of carbon distribution in The Bahamas signifies where blue carbon storage occurs, with darker blue representing greater carbon storage per grid cell and lighter blue less carbon storage. Two things become apparent from this visual representation; first, the light blue color makes up a large area (low carbon storage), and second, Andros has the greatest concentration of dark blue (high carbon storage) (Figure 9).

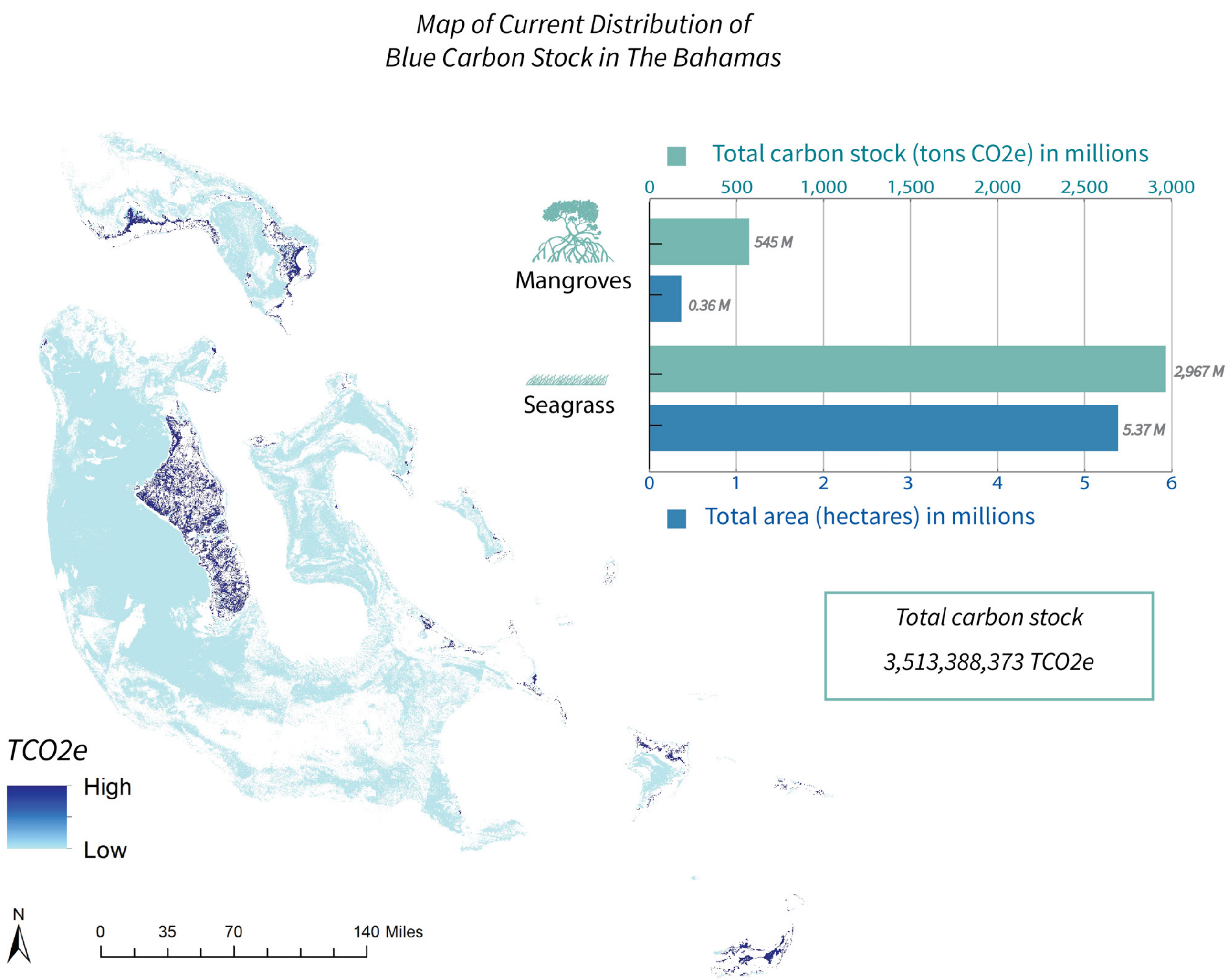


FIGURE 9. | MAP OF BLUE CARBON STOCK IN THE BAHAMAS (WITH MANGROVE BIOMASS VARIATION)

There are 5,748,143 hectares (ha) of blue carbon habitats in The Bahamas, with 93.5% comprised of seagrasses (5,379,437 ha), while mangroves make up the remaining smaller area of 6.41% (368,706 ha). Similarly, seagrasses are the largest contributors to carbon stock in The Bahamas, containing 84.5% (2,967,962,589 t CO2e) and mangroves containing 15.5%(545,456,902 t CO2e) of total carbon stock (3,513,388,373 t CO2e). Although mangroves contain more carbon on a per hectare basis than seagrasses, seagrasses occupy a larger spatial extent in The Bahamas and are therefore a significant component of blue carbon stock.

On Andros Island, the total blue carbon stock at the baseline analysis year of 2015 exceeds 1 billion t CO2e (1,011,041,687 t CO2e). There are 1,267,797 hectares (ha) in total of blue carbon habitats currently on Andros, comprised 22.1% of mangroves (282,975 ha), and 77.8% of seagrasses (993,822 ha). However, mangroves contribute the greatest to carbon storage on the island, making up 69.6% (704,150,708 t CO2e) compared to seagrasses 30.3% (306,890,978 t CO2e) of total carbon storage on Andros.

Mapping the spatial distribution of carbon stock further allows for comparisons across districts. Our results find that the Central Andros has nearly twice as much carbon (506 million metric tons CO2e, MMTCO2e) as the next largest sub-region, South Andros (264 MMTCO2e), followed by North Andros (141 MMTCO2e) and Mangrove Cay (97 MMTCO2e). This makes sense as Central Andros is the largest sub-region by area.

Map of Current Distribution of Blue Carbon Stock on Andros Island

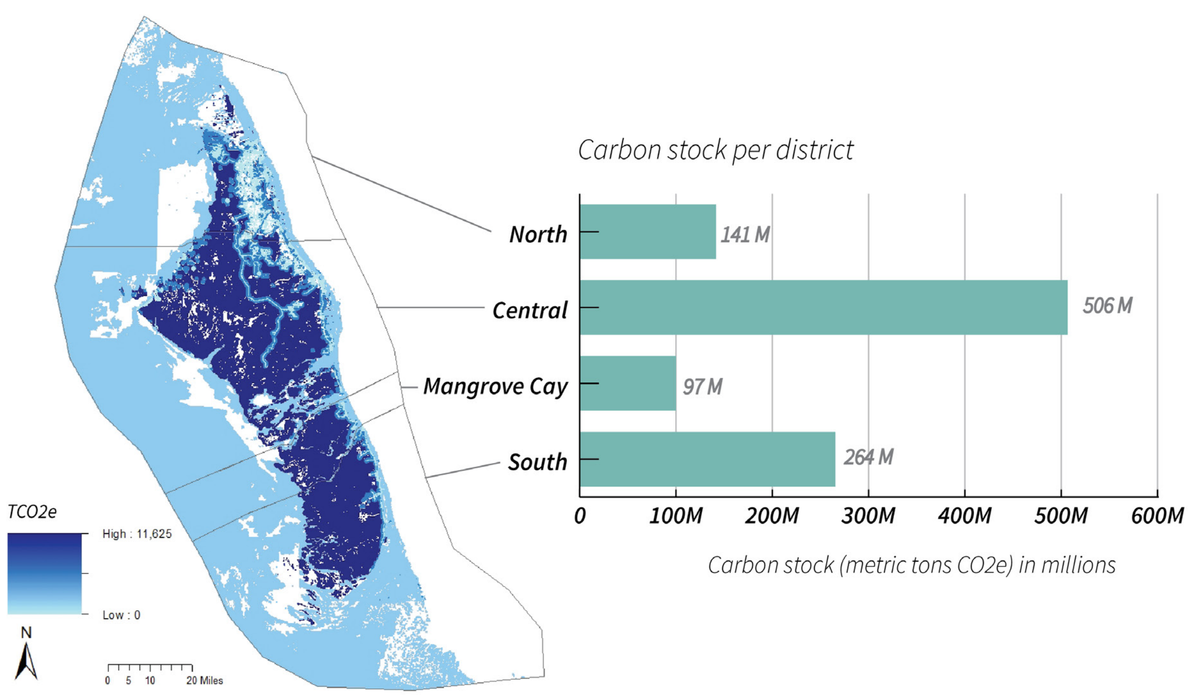


FIGURE 9. | MAP OF BLUE CARBON STOCK ON ANDROS ISLAND, SNAPSHOT OF CURRENT SCENARIO AND PER DISTRICT.

3.2 Total net carbon sequestration across four scenarios

This analysis also produced a series of maps illustrating how blue carbon storage and sequestration vary across different future management scenarios on Andros (Figure 11). Total net sequestration values are presented for a 25-year time horizon, which represent the difference between accumulation of carbon in soils if the blue carbon habitat remains undisturbed across transition years and emissions of carbon if blue carbon habitats undergo a future change by disturbance.

The business as usual (BAU) scenario represents the future scenario in which stressors, including both human activities as well as sea level rise, continue on their current trajectory with no new policies and little investment in major infrastructure. In this scenario, the analysis informs that total net sequestration provides an additional 63.9 MMTCO2e removed from the atmosphere and stored in blue carbon habitats over 25 years, at an average rate of sequestration of 2.5 MMTCO2e per year. This value is equivalent to the carbon emissions of removing 500,000 cars in the United States per year (based on the U.S. EPA Greenhouse Gas Emissions from a Typical Passenger Vehicle fact sheet, where 1 passenger vehicle emits 4.7 metric tons in 2014). To provide some context, Table 1 provides emissions equivalents of a typical vehicle to net sequestration averaged across a yearly basis under several future scenarios.

However, this sequestration and storage does not occur uniformly across Andros. The greatest total net sequestration in this scenario occurs in Central Andros (24.5 MMTCO2e), followed closely by South Andros (23.5 MMTCO2e), followed by Mangrove Cay (7.9 MMTCO2e), which stores more blue carbon than North Andros (7.6 MMTCO2e), even though North Andros has more than 2.6 times the area as Mangrove Cay. By observing the spatially explicit extent of sequestration and emissions on the map, it becomes clear that North Andros has more emissions and well as less carbon storage compared to the Mangrove Cay. This could likely be driving the reason why North Andros has comparable carbon sequestration to Mangrove Cay even though it occupies a much larger spatial area.

Yearly US car emissions equivalents

BUSINESS AS USUAL
2.5 MMTCO2e/year
- 500,000 cars per year

CONSERVATION
4.5 MMTCO2e/year
- 950,000 cars per year

INTENSIVE DEVELOPMENT
9.6 MMTCO2e/year
***Adding** 2 million cars per year*

SUSTAINABLE PROSPERITY
4.3 MMTCO2e/year
- 900,000 cars per year

Table 1 | Yearly US car emissions equvalents based on US EPA Greenhouse gas emissions of typical passenger vehicle (2014)

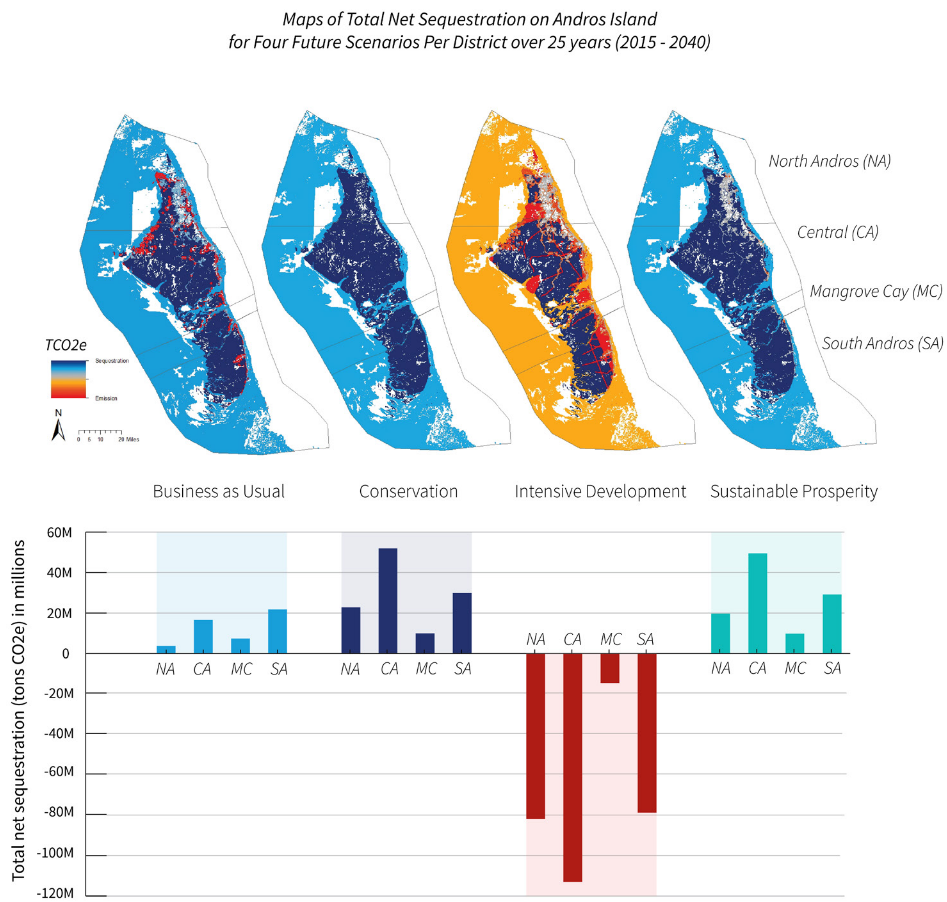


FIGURE 11. | MAPS OF BLUE CARBON TOTAL NET SEQUESTRATION ACROSS FOUR FUTURE SCENARIOS AND GRAPH OF TOTAL NET SEQUESTRATION PER DISTRICT, TOTAL VALUES OVER A 25 YEAR TIME HORIZON.

The conservation (CON) scenario represents a future in which conservation is prioritized over economic development. This scenario presents the greatest total net sequestration of 114 MMTCO2e, at an average rate of 4.5 MMTCO2e per year, which is equivalent to the carbon emissions of removing 950,000 cars in the United States per year (US EPA 2014). In this scenario, carbon storage and sequestration are correlated to total area of each district, with larger districts containing more carbon sequestration. Central Andros contributes the most to carbon storage (51 MMTCO2e), followed by South Andros (29.8 MMTCO2e), North Andros (22.7 MMTCO2e) and Mangrove Cay (9.9 MMTCO2e). Because this scenario does not include new development, there are no emissions that occur and all coastal blue carbon habitats continue to sequester and store carbon.

The intensive development (ID) scenario represents a future where priority is given to large economic development without specific protections for habitats or species. Examples of intensive development include a cruise ship port on North Andros, increasing numbers of large coastal developments such as hotels, expanded mining and a construction of sea wall along the entire eastern coastline. This scenario produces total net carbon emissions of 241 MMTCO2e, at an average of 9.6 MMTCO2e emissions per year, which is equivalent to the carbon emissions of adding 2 million cars to the road per year (US EPA 2014) for 25 years. This yearly average is 2.5 times more than the entire Bahamas emitted in 2014 (US IEA). Central Andros emits the most in this scenario (90 MMTCO2e), with North Andros emitting more (70 MMTCO2e) than South Andros (67 MMTCO2e), and lastly Mangrove Cay (12 MMTCO2e). In every district, carbon is no longer being stored by mangroves or seagrasses, but instead the carbon they stored in their biomass and soils is being emitted at an exponential decay rate. High-impact disturbance, such as dredging or mining, is likely to disturb and even remove soil carbon, leading to high levels of emissions.

The sustainable prosperity (SP) scenario refers to a future where economic development is combined with conservation goals and provides growth in critical infrastructure but aims to achieve a nature-based economy. Examples of activities in this scenario are small to mid-sized locally owned businesses, community agriculture, and mangrove restoration efforts are primarily for shoreline protection and lobster habitat. This scenario provides total net sequestration of 108 MMTCO2e over 25 years, at an average of 4.3 MMTCO2e per year, which is greater than the total emissions of The Bahamas in 2014 (US IEA). The largest contributors of carbon sequestration come occur in Central Andros (49.7 MMTCO2e), South Andros (29 MMTCO2e), North Andros (19 MMTCO2e) and Mangrove Cay (9.6 MMTCO2e). While this scenario includes carbon emissions due to activities that increase development along the eastern coastline, there is an overall net gain in carbon storage, 118% more than the amount of carbon stored from the business as usual scenario, and provides nearly 95% of the total net sequestration offered by the conservation scenario.

3.3 Net present economic value of carbon across four scenarios

Net present value (NPV) varied among future management scenarios (Figure 12). Using a carbon price of US $10 per ton of CO2e, we found the conservation scenario generated the highest economic value of $3.81 billion in potential economic returns over 25 years, which is equal to $152 million a year. The sustainable prosperity scenario also generated large economic returns of $3.63 billion over 25 years, equivalent to $142 million per year. The intensive development scenario resulted in net economic opportunity loss of $28 billion dollars, equal to a $1.1 billion loss each year. The results presented in Figure 12 are normalized to the Business as Usual (BAU) scenario under the assumption that economic gains or losses would depend on changes in management from the status quo of BAU.

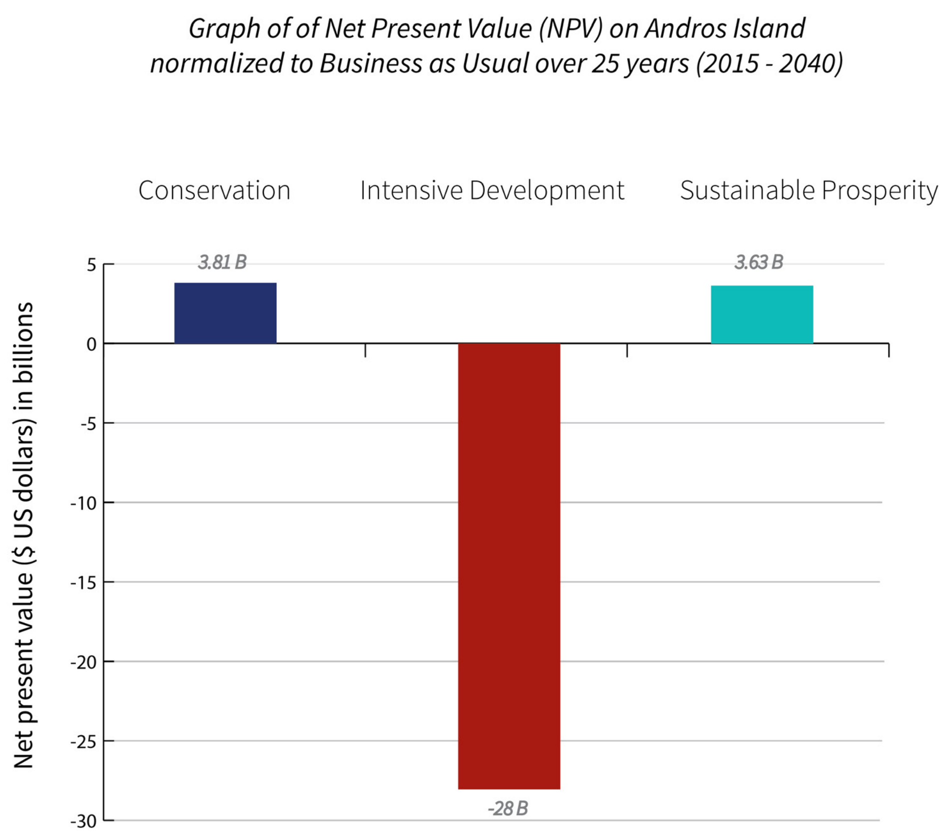


Figure 12. | Net present value of carbon based on a $10 per ton price of carbon for conservation, intensive development and sustainable prosperity future scenarios, normalized from the Business as Usual scenario for a 25 year time horizon.

In this analysis, I also provide economic values for each scenario using carbon prices of $10, $13, and $40 (Table 2). These prices reflect different potential opportunities to utilize blue carbon resources. For example, the California cap-and-trade carbon market has a floor carbon permit price of $10 and is selling permits at $13 (as of May 2017). These table values represent what Andros could potentially stand to gain if they were part of these markets and had the appropriate monitoring, enforcement, and political willingness to participate. The $40 carbon price represents the "social cost of carbon" (SCC), which refers to the cost of damages that carbon emissions have on global populations. The SCC value is useful in thinking about the global social implications of blue carbon as either carbon sinks to store atmospheric CO2, such as in the conservation or sustainable prosperity scenario, or alternatively as a major global contributor of carbon emissions, such as the intensive development scenario. Using these three carbon price values, we find the NPV from potential carbon credit gains at the conservations scenario ranges from US $ 3.8 billion – $ 15.2 billion and sustainable prosperity US $ 3.6 billion – $ 14.5 billion over 25 years, while the intensive development scenario represents economic losses ranging from $28 billion to $120 billion.

Net Present Value (NPV) on Andros Island for Carbon Prices of $10, $13, and $40 normalized to Business as Usual over 25 years (2015 - 2040)

Future Scenario	***Net present value at three alternative carbon prices***		
	$10	***$13***	***$40***
Conservation	*$ 3.8 billion*	*$ 4.9 billion*	*$ 15.2 billion*
Intensive Development	*$ -28 billion*	*$ -36.4 billion*	*$ -120 billion*
Sustainable Prosperity	*$ 3.6 billion*	*$ 4.7 billion*	*$14.5 billion*

Table 2 | Net present value of carbon accumulation based on a $10 per ton price of carbon for conservation, intensive development and sustainable prosperity future scenarios, normalized from the business as usual scenario for a 25 year time horizon.

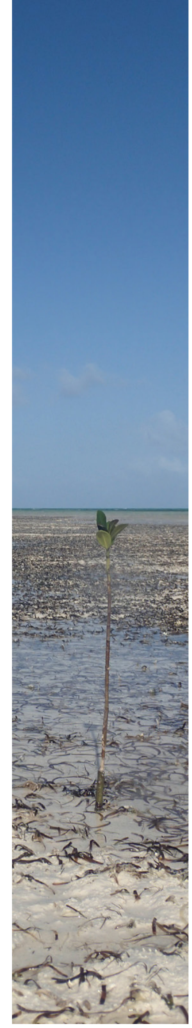
5.

DISCUSSION: BLUE CARBON AND CONSERVATION

How can blue carbon further conservation?

The results of this analysis provide maps with spatially explicit values on the current distribution of blue carbon habitats in The Bahamas and Andros, and inform how future management scenarios can have profound impacts on the delivery of blue carbon storage and sequestration services. By utilizing available habitat spatial layers, literature values for carbon in coastal habitats, access to future development scenarios, and the publicly available InVEST coastal blue carbon model, this analysis served to provide a first-order approximation of blue carbon services in The Bahamas. By informing the distribution and spatial variation of blue carbon services currently and across alternative future development scenarios, this study provides insight into how a blue carbon analysis can be performed, replicated, and utilized to contribute to further conservation goals.

I believe this analysis provides an opportunity to utilize blue carbon through a portfolio of options that range from direct government incentives, to direct local incentives, and finally to broader indirect altruism to enhance conservation goals by promoting green "pro-social" behaviors. In the discussion below, I highlight how this analysis could potentially be used across the proposed blue carbon portfolio of options.



5.1 DIRECT GOVERNMENT INCENTIVES

One of the major challenges of conservation is generating and sustaining adequate funding to protect and enforce natural areas. Further challenges arise when the opportunity cost, i.e. the value of the next best alternative, is high, such as the opportunity cost of protecting coastal habitats when an alternative use for the land could be, for example, a mega-development that generates large, relatively short-term economic returns. In The Bahamas, mangroves and seagrasses face growing threats from increasing coastal development, such as hotels, marinas, harbors, and urban sprawl, which was learned through both literature review as well as personal correspondence with government official about current threats.

Even in situations where government officials may be aware of their coastal resources and have a desire to provide more coastal resource protections, as observed during our meetings with government officials in The Bahamas, governments face enormous pressures to facilitate economic growth for their citizens and must make decisions, which usually favor more immediate economic returns. In recent years there has been a rise in financial mechanisms that provide economic incentives designed to reduce global carbon emissions due to the multitude of negative effects that high atmospheric carbon dioxide concentrations have on our global climate and oceans, including sea level rise, increasing storm surges and severity, fisheries impacts and others. Below I provide some insight into how this work could inform potential direct government incentives to conserve coastal habitats based on a blue carbon analysis.

5.1.1 Carbon markets

Carbon markets can refer to a variety of mechanisms that may sell and trade permits at a maximum allowable emissions level or offer carbon offset credits to incentive others to retain or restore carbon rich habitats, such as forests and rainforests. While not all of these mechanisms have yet to fully incorporate blue carbon as a possible carbon offset or tradeable permit, there is growing interest from scientists and others (Murray et al. 2011, Locatelli et al. 2014) for current frameworks to further build blue carbon into their programs. A blue carbon analysis, such as the one presented in this study, could be useful in providing the necessary first-steps in expanding dialogue on including blue carbon in carbon markets and emissions reductions strategies. Results from a blue carbon analysis can inform the government about the long-term potential economic gains that are possible with meaningful conservation of blue carbon habitats.

Examples of carbon markets with potential for blue carbon inclusion include the United Nations Framework Convention on Climate Change (UNFCC) process through either the Clean Development Mechanisms (CDM) or Reducing Emissions from Deforestation and Degradation (REDD). However, both require strict monitoring and accounting protocols, which can be difficult for small island countries to meet. Furthermore, a recent review of blue carbon projects around the world drew conclusions based on financial mechanisms currently, suggested there are other viable alternatives to the UNFCC mechanism that are currently more cost-effective and easier to implement, particularly for small coastal communities (Wylie et al. 2016).

The California cap-and-trade market is a compliance market currently operating across California, and has recently linked with Quebec and Ontario in Canada. The California carbon permit sold for $13 per ton CO_2e in May 2017, and this analysis provides insight into how blue carbon sequestration on Andros could potentially provide $4.3 – 4.6 billion over the course of 25 years for financing conservation in this market if the conservation or sustainable prosperity future management scenario are taken.

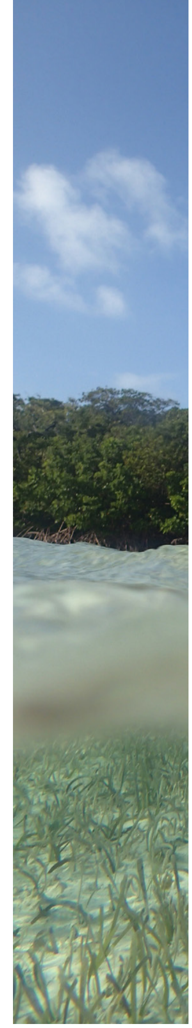
Carbon credits can also be sold on voluntary carbon markets, which include numerous buyers, the largest of which is the Verified Carbon Standard (VCS) (Hamrick and Goldstein 2016). The review by Wylie et al. 2016 provided examples of blue carbon projects that are currently using the voluntary carbon market. While voluntary markets also require a level of standardization, they often do not necessitate the same level of rigorous monitoring required by multi-lateral mechanisms of CDM and REDD+. In this way, voluntary markets provide more accessibility for countries to engage in carbon offset programs, as the barriers to entry are lower. However, a downside is that the prices for voluntary markets are generally much lower than other compliance markets. In 2015, the average price of the voluntary market was $3.3 per ton carbon (an all time low), but prices have averaged $1 $12+ per t CO2e. Additionally, because the voluntary market is self-regulated, there are further risks of engaging in potentially fraudulent credits due to the lower requirements of participating in these programs.

The use of $10 per ton CO2e in this analysis was meant to demonstrate a possible upper bound on voluntary market prices, as well as provide an easily scalable value that can be adjusted to compare how Andros NPV could possibly be used in voluntary carbon markets. On Andros, using $10 per ton CO2e price provides major economic returns for the conservation or sustainable prosperity scenario, between $3.6 – 3.8 billion over 25 years. By producing an analysis that is replicable, my hope is that other countries may be able to better evaluate their blue carbon resources and determine if carbon markets may be a potential strategy for financing blue carbon conservation.

5.1.2 Pathway to INDC Paris Accord pledge

Another option for countries to utilize the value of their blue carbon resources is to consider how long-term sequestration from management of coastal habitats can help countries reach their Intended Nationally Determined Contribution (INDC) under the UNFCC Paris Climate Accord. In 2015, The Bahamas provided its INDC outlining its plans to reduce carbon emissions by a minimum of 30% below 2002 levels. In 2002, The Bahamas emitted 3.42 MMTCO2e (US EIA), and a 30% reduction would mean a decrease in emissions (or net sequestration) of 1.026 MMTCO2e. According to our analysis, if The Bahamas followed the future management scenarios of business as usual, conservation, or sustainable prosperity, they would see a decrease in emissions of 2.5 MMTCO2e, 4.5 MMTCO2e, or 4.3 MMTCO2e per year, respectively, on average.

While further research on blue carbon storage and sequestration values on Andros and in The Bahamas would be necessary to formally utilize blue carbon as a pathway to reach its INDC Paris pledge, this analysis provides insight into the potential value of blue carbon in meeting international treaties. Furthermore, protecting blue carbon resources is increasingly being considered one of the most cost-effective means of emissions reductions (Murray et al. 2011), and should be considered when countries evaluate a range of options in decreasing emissions. Countries with a wealth of coastal habitats and blue carbon storage potential, which are likely to be island nations, may be in a tremendous position to take advantage of their blue carbon resources as a means for both national emissions reductions as well as a conservation finance mechanism.



5.2 DIRECT LOCAL INCENTIVES

While blue carbon falls among the definition of ecosystem service due to its role in regulating gas exchange and climate, it differs from other kinds of ecosystem services in a critical way. Unlike other ecosystem services, the benefits of protecting blue carbon habitats are not directly available to those who have taken local actions of protection. For example, protecting an ecosystem service such as an important nursery grounds for fish yields paybacks to local communities who can often directly benefit from their actions by increased fish catches. However, local actions in protecting ecosystems for their blue carbon services, on the other hand, yields benefits to the global human world because its impact on the climate and emissions reductions affects, and benefits, everyone. For this reason, blue carbon offers a unique opportunity to build on this relationship between local actions and global impacts through a variety of options that potentially bring local benefits back to communities who protect blue carbon habitats by advertising how these actions serve the global good.

5.2.1 Marine Protected Area (MPA) siting

An example of how blue carbon can potentially provide local incentives for conservation can be observed through the process of siting new marine protected areas (MPAs). In The Bahamas, roughly 10% of coastal or ocean resources are currently in MPAs and the government and core partners are in the process of expanding the MPA network an additional 10% to reach 20% by 2020 as part of the Caribbean Challenge Initiative (CCI). While there are many considerations in deciding where to designate new MPAs, such as ecosystem services including coastal protection, critical habitat for fisheries, tourism and recreation value, and biodiversity hotspots, blue carbon can be another useful metric in determining where to site new MPAs. Because blue carbon services are provided by coastal habitats such mangroves and seagrasses, they intrinsically provide co-benefits and other services due to their multi-functionality. In this analysis, I produced a map of total blue carbon stock in The Bahamas, and it is possible to observe spatial heterogeneity in mangrove aboveground biomass due to the modeled mangrove biomass values.

I further expanded on this analysis by overlaying The Bahamas current MPA network with the spatial distribution of blue carbon (Figure 13) and found that the current MPA network contains roughly 14% of total blue carbon in The Bahamas, of which 56% is contributed by mangroves and only 4% by seagrasses. Throughout this analysis, I have observed a trend in the significance of seagrasses in contributing to blue carbon due to their extensive range. Further research is necessary to understand the different levels of protection among specific MPAs and how those may influence blue carbon. However, by using the spatially explicit values provided by the coastal blue carbon model, blue carbon can be used as further rational for designating new MPAs. This can incentivize governments due to blue carbon contributions to emissions reductions, as well as local communities as beneficiaries of MPAs are often locals. Using blue carbon to help guide new MPA designations can also provide local incentives for using blue carbon to further conservation.

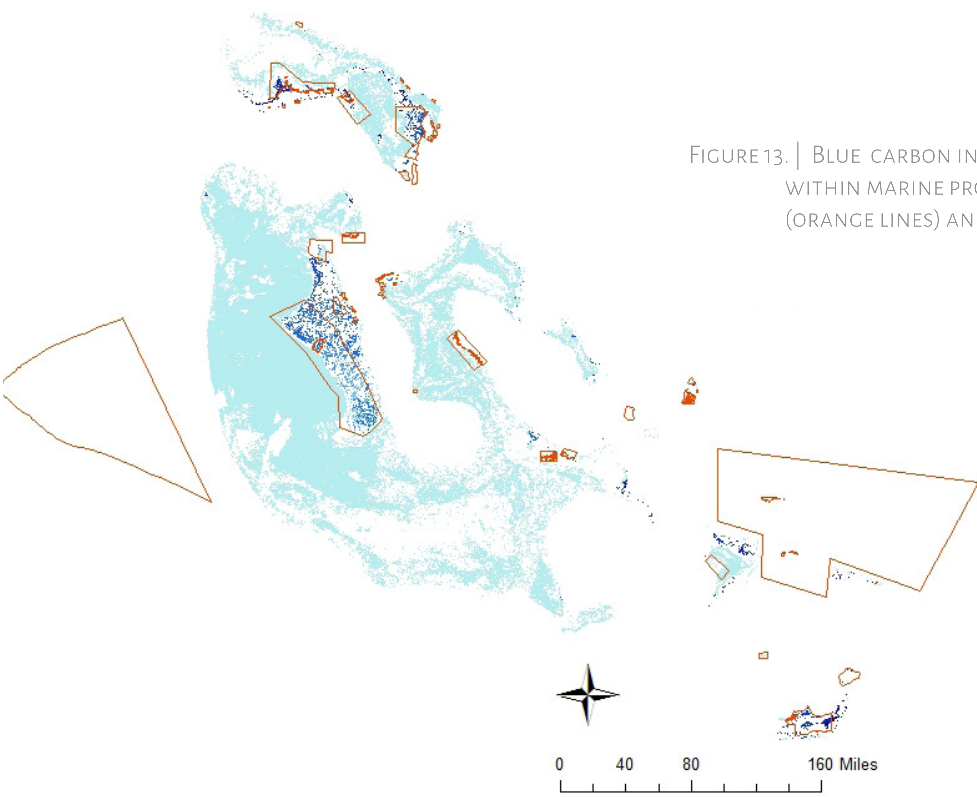


FIGURE 13. | BLUE CARBON IN THE BAHAMAS WITHIN MARINE PROTECTED AREAS (ORANGE LINES) AND OUTSIDE

5.2.2 "Blue" tourism

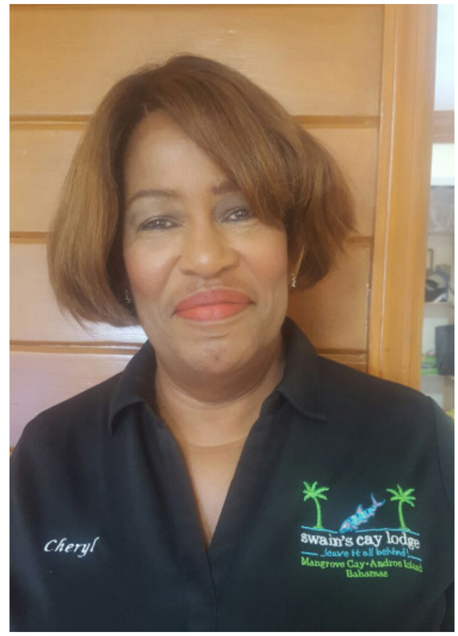
Building off the idea of blue carbon furthering the "global good" as presented in the section above, another avenue to potentially link the benefits of blue carbon's global gain to local actions is considering blue carbon as a way to advertise and capitalize on the growing trend of "responsible" tourism. Tourism is the largest global service industry in the world, making up US $ 7.2 trillion, or 9.8% of the world's GPS in 2015 and is expected to grow an additional 4% over the next ten years (WTTC 2016). In The Bahamas, tourism is the largest economic sector employing over 50,000 people and making up 50-60% of the nations GDP (Dupuch 2004). Furthermore, there is a trend towards a new wave of tourism where individuals have a higher level of environmental and cultural awareness and seek opportunities that are more fulfilling and enriching (UNWTO 2015). Niche markets in tourism are beginning to broaden, as people are seeking a variety of different travel experiences ranging across ecotourism, ethical tourism, responsible tourism and sustainable tourism. Responsible tourism is defined as "tourism that maximized benefits to local communities, minimized negative social or environmental impacts, and help local people conserve fragile cultures and habitats or species" (City of Cape Town 2002).

Two components from this study stand out as providing opportunities to market blue carbon conservation as "blue tourism" for The Bahamas. The first is based on discussions with government officials regarding the topic of marketing blue carbon through tourism. According to officials, The Bahamas currently markets their country across a wide range of tourism destinations, from being a "honey-moon" destination, to "boating haven" and "bonefishing fishing" destinations and more recently an "ecotourism" destination, among others. What they lacked was a singular marketing perception for The Bahamas.

This is where blue carbon could potentially play a role. If The Bahamas prioritized action on conservation that served to retain blue carbon habitats and marketed their island as a "blue tourism" destination, they may be able to play off their current array of tourism activities while also giving themselves a definitive brand of "blue tourism." This brand could be: "by traveling to The Bahamas, you are contributing to local communities who protect blue carbon for the greater global good, and contribute to the nation's economy, which takes a leadership role in protecting blue carbon resources." This could then become a local incentive using blue carbon as increased tourism can benefit local communities when done in a responsible and appropriate way.

The second component of this analysis that could be useful in furthering the idea of "blue tourism" would be utilizing the results from the national and Andros assessment to promote total area of blue carbon habitats protected. For example, similarly to the MPA siting, a blue carbon analysis can inform a country about the distribution of blue carbon and where they are currently protected. The case study on Andros provides a further unique opportunity to market avoided emissions if the conservation or sustainable development alternatives were implemented. For example, The Bahamas could potentially advertise that their management decisions led to avoided emissions of the intensive development scenario of 241 MMTCO2e over 25 years, equivalent to adding 2 million cars to the road every year for 25 years (US EPA 2014).

Through this option, blue carbon can provide an opportunity for local communities who take actions to protect coastal habitats to capitalize on this effort and market their communities as demonstrating a commitment to responsible practices and encourage travelers seeking responsible or ethical tourism experiences to recognize The Bahamas as taking a leadership role in this new tourism arena.



Freeman, Nathan's Lodge

KEMP'S BAY, SOUTH ANDROS

A resident all his life, Freeman shared with me his story about the challanges of getting freshwater on Andros. Traditionally, people have dug wells to reach the groundwater, but recently water has begun corroding the pipes. He once had an ice machine that stopped working, only to find crystalized salt on the inside. They now import water from Nassau and pipes are being constructed to carry water to residents. There is a need for development, but wisely.

Jesse and Chelsea

ANDROS BEACH CLUB, SOUTH ANDROS

Living here for 14 and 9 years, respectively, Jesse and Chelsea take visitors who stay at their boutique resort diving, snorkeling, fishing, or exploring the blue holes of Andros. They told me that conservation has become more important in recent years as it has seen residents, such as bonefishing guides, benefit them more.

"The people here want to be known as 'the nature island' - they want to keep their resources."

Cheryl, Swain's Cay resort

MANGROVE CAY

Originally from Mangrove Cay, Cheryl spent some time on New Providence Island in Nassau for a while before returning to Mangrove Cay to open the Swain's Cay Resort. It was a dream, she told me, to start up and run the business she created. Offering kayaking, nature walks, visits to blue holes, and a beautiful view of the beach, there is no doubt people are drawn to the natural beauty and charm of Andros island and its residents.

TABLE 3 | Insights from Local Androsian residents who depend on their natural resources and rising interest in tourism

Furthermore, a blue tourism analysis in The Bahamas through this concept of "blue tourism" could be used to help provide a rational on why coastal habitats could be considered more economically beneficial to Bahamians over large mega-developments if an appropriate link was made between blue carbon protection and an increase in tourism, their largest economic driver. In this case, blue carbon could be a driver of conservation efforts through "blue" tourism, where both local economies gain from increased responsible tourism, everyone gains from reduced emissions, and habitats have further recognition and reason to be conserved for the future.

5.2.3 Sustainable development planning

The precursor to this study was a series of analyses conducted by The Natural Capital Project, Nature Conservancy, Office of the Prime Minister (OPM) and core partners in The Bahamas, with funding from the Inter-American Development Bank (IDB) to develop a master plan for sustainable development on Andros. Andros is the largest island in The Bahamas and one of the biggest in the Caribbean. Yet it has a relatively small population and is considerably undeveloped. Although Andros is politically considered a single island, is it actually made up of three main islands: North, Mangrove Cay, and South. Large bights in between islands make travel for visitors, and even locals, challenging. For example, it is not possible to easily travel between the three main islands without charting a plane or boat. Furthermore, there is a need by the locals for improvements in critical infrastructure and functional developments while also retaining their natural resources (Table 3).

A blue carbon analysis can further play a role in sustainable development planning by providing spatially explicit maps of where human activities or stressors are likely to impact coastal habitat functioning. For example, based on this analysis, in all scenarios, except conservation, the future alternatives include places where both carbon sequestration and carbon emissions occur. Understanding how these processes vary spatially at different intensity levels can provide insight into where future developments should be potentially avoided to retain the carbon storage services provides by blue carbon habitats. In all but the conservation scenario, most development and therefore disturbance to blue carbon occurs in the North and Central Andros. Further research with details on specific carbon content and biomass distribution on Andros could help inform where large carbon reserves occur and potentially prioritize their conservation, while an analysis can also highlight places that have little carbon services and do not contributes significantly to the net sequestration.

This can be connected back to "blue" tourism, as sustainable development planning ideally includes the value of coastal resources in providing services and contributing back to the economy.

5.3 INDIRECT ALTRUISM

While direct government and local incentives may offer more straightforward approaches to using blue carbon for conservation, there is also an opportunity to broaden the scope of impact by thinking about the value of blue carbon in promoting altruistic behavior. Altruism refers to behavior by an individual that serves the greater good and can be considered selfless actions or taking actions for the good of humanity. This concept has already been discussed in section 5.2.2 “Blue” tourism; however, it is worth exploring in a little more detail.

Across the literature, there is both support for and criticism of direct economic incentives such as the use of carbon markets as a means to truly reduce carbon emissions and finance blue carbon conservation. Criticism about economic incentives have been raised questioning whether these mechanisms can influence the overall reduction of carbon emissions, as opposed to simply “paying to pollute” and moving emissions from one place to another. Another criticism is the inability of these markets to support actions that promote long-term sequestration or contribute to meaningful behavioral changes that are necessary for our society to become more sustainable. Due to these uncertainties in how carbon markets may play a role in furthering conservation, I offer some perspectives in how indirect altruism could be yet another option in the portfolio of options listed above.

There may be an opportunity for considering the use of blue carbon to further conservation by appealing to the “greenness” of others and the concept of “pro-social” behavior. There is considerable research in the psychology literature regarding how and why people make decisions based on a variety of different factors (McKenzie-Mohr and Schultz 2014). This research alludes to evidence that it is often not knowledge, facts, or even economic incentives alone that drive people to make or change their decisions, but instead reasons relating to goal setting, social norms, prompts, incentives, and feedbacks, among others (McKenzie-Mohr and Schultz 2014). For this reason, using the “global good” notion of blue carbon and appealing to more innate, human, and social aspect of people may lead to an opportunity for changing perceptions about our interaction with nature and potentially societal shifts in better managing natural resources into the future.

5.3.1 Raise awareness

Using blue carbon to further conservation requires that the concept of blue carbon becomes better understand and more widely acknowledged and accepted by governments and the public. According to recent research on knowledge gaps in blue carbon, the term “blue carbon” itself often leads to confusion as it can refer to both the biophysical components of coastal habitat carbon storage and sequestration, or be used for advocating broader financial or economic incentives (Thomas 2014). Furthermore, coastal habitats provide a variety of co-benefits, and there is a huge opportunity to more broadly communicate both blue carbon and the numerous other ecosystem services coastal ecosystems provide as valuable to the world.

From this analysis, various data outputs can be used to communicate the value of conserving blue carbon. For example, by highlighting the comparison of net sequestration of Andros across future development scenarios, where sustainable prosperity led to total net sequestration of 108 MMTCO2e over 25 years, or 2.5 MMTCO2e per year, equivalent to removing 900,000 cars from the road each year for 25 years (US EPA 2014), it is possible to draw comparisons and demonstrate the magnitude of impact coastal blue carbon protections can have on mitigating carbon as well as the need to reverse the trends of coastal destructions occurring around the world.

5.3.3 International leadership

Lastly, I would like to briefly highlight another potential avenue of indirect altruist behavior that could lend itself to further blue carbon conservation based on an understanding of blue carbon resources and improved management. As discussed above in section 5.1.2 Pathway to INDC Paris Pledges, there is growing international consensus about the need for effective climate mitigation approaches and concern about the rapid climate changes that are occurring.

According to The Bahamas INDC, their contribution of carbon emissions is negligible on a global scale. As a small low-lying island nation, The Bahamas is at risk from climate change impacts, including increasing hurricanes, storm surges, saltwater intrusion, and sea level rise. However, if The Bahamas were to emphasize coastal protection on the basis of blue carbon (and their co-benefits), they could leverage the fact that they are a nation who has contributed very little to global emissions, but is making major proactive commitments to contributing to global carbon sequestration through retaining their large blue carbon resources. In doing so, The Bahamas could stand up as a leader on climate change, particularly as other major nations have fallen to the wayside in climate leadership, such as the United States recent proclamation of exiting the Paris accords. By adding to the global solution for climate change by conserving blue carbon, The Bahamas could serve as an example for other island nations to make serious commitments to conserving blue carbon and use their positions to pressure and encourage larger nations who are contributing more emissions to consider their role in the global climate crisis.

A PORTFOLIO OF BLUE CARBON OPTIONS

DIRECT GOVERNMENT INCENTIVES

- Carbon markets
- Pathway to Paris INDC Pledge

DIRECT LOCAL INCENTIVES

- MPA siting
- “Blue” tourism
- Sustainable Development Planning

INDIRECT ALTRUISM

- Raise awareness
- International leadership

6. CONCLUSIONS

In this report above, I have attempted to utilize an analysis of blue carbon in The Bahamas and Andros to better understand the various ways blue carbon can be used to further conservation goals and contribute to sustainable economic development. In conducting this analysis, I gained insight into the spatial distribution of blue carbon stock across The Bahamas and on Andros, as well as how carbon may change under several future management scenarios in total net sequestration as well we net present value of each scenario. Using spatially explicit outputs from the coastal blue carbon model, I provided a portfolio of options, from direct government to local incentives, as well as indirect altruistic avenues in which a blue carbon analysis could be used to further inform, or at least begin productive discussions about the value of blue carbon and potentially lead to more in-depth research at the local scale about blue carbon within individual countries or regions.

While this analysis and the results presented above lack the robustness to be used to implement some of the portfolio of blue carbon options, such as carbon markets or carbon offsets due to their stricter requirements on carbon sampling and monitoring, I believe this analysis provides a range of useful avenues for opening discussions about blue carbon. Furthermore, across the portfolio of options, it is my hope that different countries can take avenues or a blend of conservation approaches that best suite their specific needs and further blue carbon conservation while contributing to the global good.

STAKEHOLDER ENGAGEMENT + MAPPING ECOSYSTEM SEVICES OF BLUE CARBON = A PORTFOLIO OF CONSERVATION SOLUTIONS

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